(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 959 485 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
24.11.1999 Bulletin 1999/47

(51) Int. Cl.[6]: H01J 1/30

(21) Application number: 98870112.4

(22) Date of filing: 18.05.1998

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE
Designated Extension States:
AL LT LV MK RO SI

(71) Applicant: BARCO N.V.
8970 Poperinge (BE)

(72) Inventor: Verstraete, Gerrit
8740 Pittem (BE)

(54) Cold cathode electron-emitting device

(57) A cold cathode electron-emitting device (1) comprises a Schottky junction (6) between a thin n-type semiconductor layer (5) and a metal electrode (4), and is exposed to a vacuum. A voltage which is positive with respect to the metal electrode (4) is applied to the n-type semiconductor layer (5) so that the Schottky junction (6) becomes reverse biased to a degree that electrons are injected from the metal electrode (4) into the conduction band of the n-type semiconductor layer (5) by tunnelling. After having travelled through the n-type semiconductor layer (5), a part of the electrons still have enough energy to bridge the electron affinity of the n-type semiconductor layer (5) and are injected into the vacuum. The electron affinity, band gap, thickness and impurity concentration of the n-type semiconductor layer (5) are important parameters for the electron emission to be efficient.

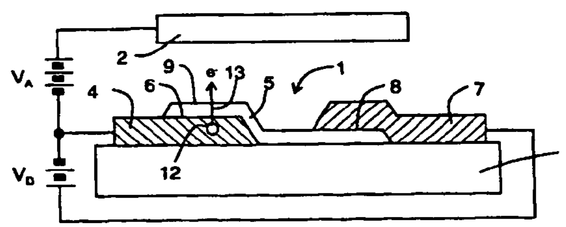

Fig. 1

EP 0 959 485 A1

Description

Technical field of the invention

[0001] The present invention relates to cold cathode electron-emitting devices, in particular to technologies for the construction of cold cathode electron-emitting devices, which can emit electrons into a vacuum. Cold cathode electron-emitting devices are used in applications such as flat panel displays.

State of the art

[0002] For the cold emission of electrons into a vacuum, various methods, technologies and devices based on various physical phenomena are known.

[0003] Spindt Cathodes, as known in the art, are based on field emission from tips of cone-shaped structures of a material with a low work function and are used in e.g. FEDs (Field Emission Displays). The anode voltage and control voltage needed for the emission of electrons are both relatively high (respectively above 100 volts and 20 volts).

[0004] Surface conduction electron emission (SCE) devices are disclosed in EP 0343645, US 5285129 and US 3916227. SCE devices have a low emission efficiency (typically less than 1% of the conducted electrons are injected into the vacuum) and need relatively high source voltages (above 10 volts).

[0005] Electron-emitting devices based on tunnelling of electrons through a thin insulating layer between two metals (MIM structure) or between a semiconductor and a metal (MIS structure) have been reported by Suzuki in SID 97 Digest and by K. Tahara et al. of Yokoo Lab., Tohoku Univ., Japan. The voltage needed for the referred emission of electrons through tunnelling is relatively low (between 5 and 10 volts), but the efficiency of the emission is also low because the electrons have to travel through a layer of metal wherein the probability of inelastic collisions with free electrons in the metal is high, even if the layer of metal is only a few nanometers thick.

[0006] Emission from a MISM structure is disclosed in US 5489817. A relatively high AC voltage (more than 100 volts) is needed with such a device, and the obtained emission efficiency is low because the electrons have to travel through a metal layer.

[0007] Emission from a forward biased Schottky diode has been reported by Stolte et al in Solid-State Electronics, Vol. 12, pp. 945-954 and by Swank in Journal of Applied Physics, Vol. 41, number 2, pp. 778-781. In both cases, control voltages are relatively low (about 1 volt). The emission efficiency is low because the emitted electrons have to travel through a metal layer.

[0008] Electron-emission from a reverse biased Schottky junction has been disclosed in EP 0331373. Electrons are injected from a p-type semiconductor into a Schottky electrode laying on top by avalanche breakdown. The emission efficiency is low because the electrons must travel through the Schottky electrode.

[0009] US 2960659 discloses the emission of electrons, created by avalanche breakdown in a PN-junction, or, by injection from the base into the collector of a NPN transistor. The electron emission efficiency is low because the electrons have to travel through a layer of n-type semiconductor material and through a metal layer.

[0010] US 3098168 discloses an electron-emitting device in which some electrons gain enough energy from an electric field in the bulk of a semiconductor substrate to bridge the electron affinity so that those electrons are injected immediately from the semiconductor into a vacuum. Most of the electrons are collected by a metal electrode structure on top of the semiconductor substrate, which results in a low electron emission efficiency.

[0011] All of the above mentioned cold cathode electron-emitting devices have a low electron emission efficiency and/or need a relatively high drive voltage, which can result in a high lateral spread of the velocity of the emitted electrons. Some of the cold cathode electron-emitting devices need a strong external electric field to assist the emission of electrons.

Summary of the invention

[0012] It is an aim of the present invention to provide cold cathode electron-emitting devices, which can emit electrons with a high efficiency into a vacuum and whereby the voltages to control the electron emission are low. The cold cathode electron-emitting devices are relatively easy to construct, in particular by means of thin film techniques. It is also an aim of the present invention to provide circuits for driving such cold cathode electron-emitting devices.

[0013] A cold cathode electron-emitting device is provided, which comprises at least a n-type semiconductor layer and a first metal electrode, forming a first Schottky junction. When this first Schottky junction is reverse biased, hot electrons are injected from the first metal electrode into the n-type semiconductor layer by tunnelling. The hot electrons have such an energy and the n-type semiconductor layer is of such a material that a part of the hot electrons can flow through the n-type semiconductor layer and penetrate directly from the n-type semiconductor layer into a vacuum.

[0014] According to a preferred embodiment, a cold cathode electron-emitting device is provided which, when properly driven, presents a range of operating states, such that at least 5% of the electrons which have tunnelled through the first Schottky junction are emitted into the vacuum, the voltage over the cold cathode electron-emitting device being lower than 10 volts.

[0015] Preferably, the material of the n-type semiconductor layer is of the II-VI type, such as BaO or ZnS.

[0016] Furthermore, circuits are provided for current

driving one or more of the hereabove described cold cathode electron-emitting devices. In the circuits, at least one capacitor or resistor, at least one cold cathode electron-emitting device, and at least a voltage source are combined. The at least one capacitor or resistor and the at least one cold cathode electron-emitting device may be mounted on the same substrate.

Short description of the drawings

[0017]

Fig. 1 is a cross-sectional view of a first embodiment of the present invention;
Fig. 2 is an energy diagram of a reverse biased Schottky junction in a cold cathode electron-emitting device of the invention, through which an electron current is drawn by tunnelling;
Fig. 3 is a cross-sectional view of a part of a cold-cathode electron-emitting device of the invention upon which a mono-atomic layer of a material with a low work function is deposed;
Fig. 4 is a cross-sectional view of a second embodiment of the present invention, being a symmetrical cold-cathode electron-emitting device driven by an AC-voltage source;
Fig. 5 is an energy diagram of a forward biased Schottky junction in a cold cathode electron-emitting device of the invention;
Fig. 6 is a cross-sectional view of a third embodiment of the present invention wherein a capacitor is implemented with a cold cathode electron-emitting device on the same substrate;
Fig. 7 is a cross-sectional view of a fourth embodiment of the present invention in which the n-type semiconductor layer consists of a first region with high impurity concentration and a second region with low impurity concentration.

Description of preferred embodiments

[0018] In Fig. 1 is shown a cross-sectional view of a first embodiment of a cold cathode electron-emitting device 1 according to the present invention. To the cold-cathode electron-emitting device 1 are connected an anode plate 2, a first DC voltage source V_D, and a second DC voltage source V_A, both presenting a positive and a negative terminal. On an insulating substrate 3, for instance made of glass, is deposed a first metal electrode 4. Over a part of this first metal electrode 4 and over a part of the insulating substrate 3 is deposed a n-type semiconductor layer 5. The contact between the first metal electrode 4 and the n-type semiconductor layer 5 forms a Schottky junction 6. A second metal electrode 7 is deposed over a part of the n-type semiconductor layer 5 and the insulating substrate 3. The contact 8 between the n-type semiconductor layer 5 and the second metal electrode 7 can be an ohmic contact or a Schottky junction. The second metal electrode 7 can be made of the same or of a different material than the first metal electrode 4.

[0019] According to the present invention, the Schottky junction 6 should be reverse biased for an emission of electrons from the first metal electrode 4 into the n-type semiconductor layer 5 to be possible. Therefore, the second metal electrode 7 is connected to the positive terminal of the first DC voltage source V_D. It is an aim of the present invention that as much as possible of the emitted electrons pass through the n-type semiconductor layer 5 and enter into the vacuum being in contact with the n-type semiconductor 5 at a n-type semiconductor layer to vacuum boundary (hereinafter referred to as a boundary) 9.

[0020] To collect the electrons, which leave the n-type semiconductor layer 5 into vacuum, an anode plate 2 is located in the same vacuum and is connected to the positive terminal of the second DC voltage source V_A. The voltage of the second DC voltage source V_A can be relatively low, e.g. +10 Vdc, as no electric field is needed to provoke or increase the emission of electrons into vacuum. However, the voltage of the second DC voltage source V_A will be several kilovolts in typical applications.

[0021] The voltage over the Schottky junction 6, further called V_Z, is equal to V_D minus a voltage drop V_F over the contact 8 when this contact is not an ohmic contact but a forward biased Schottky junction.

[0022] The operation of the first embodiment is further explained with the help of Fig. 2, which shows an energy diagram within the first metal electrode 4, the n-type semiconductor layer 5 and the vacuum. In the n-type semiconductor layer 5, E_V is the top energy level of the valence band, E_C is the bottom energy level of the conduction band, E_g is the band gap, E_F is the Fermi level, and E_{VAC} is the minimum energy needed for the electrons to penetrate into the vacuum at boundary 9 (also named the vacuum energy level).

[0023] When a positive voltage is applied to the n-type semiconductor layer 5 with respect to the first metal electrode 4, the Schottky junction 6 is reverse biased. The impurity concentration of the n-type semiconductor layer 5 is chosen high enough to restrict the width d of the depletion region to a few tens of nanometers. For the emission of electrons from the first metal electrode 4 into the n-type semiconductor layer 5, electrons in the first metal electrode 4 with an energy just below the Fermi level E_F have to bridge an energy barrier which is slightly larger than a minimum triangular energy barrier 11 as indicated on Fig. 2. This triangular energy barrier 11 has an energy barrier height Φ_B and an energy barrier width δ. The bridging of the energy barrier is possible by tunnelling of the electrons 12 through the energy barrier when the energy barrier height Φ_B is not too high and the energy barrier width δ not too large. The tunnelling current is exponentially related to the energy barrier width δ. A higher concentration of impurities in the n-

type semiconductor layer corresponds to a lower Zener voltage V_Z over the Schottky junction for a given tunnelling current.

[0024] After the electrons have crossed the depletion region, they have gained energy and become so called "hot electrons". According to the present invention, it is a first condition that the Zener voltage V_Z should have such a value that the product q. V_Z of the elementary electron charge (q) multiplied by the Zener voltage V_Z exceeds the electron affinity χ in the n-type semiconductor layer to vacuum boundary 9. As shown in Fig. 2, the electrons 12 which are injected from the metal electrode 4 into the n-type semiconductor layer 5 following a path 13 have then a positive residue of energy ΔE which permits them to escape into the vacuum at the n-type semiconductor to vacuum boundary 9.

[0025] However, according to the present invention, it is a second condition that the above mentioned product $q.V_Z$ is lower than the band gap E_g, so that the electrons being hot electrons when coming out of the depletion region, do not have enough energy to create electron-hole pairs in the n-type semiconductor layer 5. The hot electrons may, along their path 13 through the n-type semiconductor layer 5, due to scattering by phonons and by impurities and defects inside the n-type semiconductor layer 5, loose a limited amount of kinetic energy, however small as it regards collisions which are highly elastic.

[0026] If both first and second conditions mentioned above are met, being the product $q.V_Z$ higher than the electron affinity χ and lower than the band gap E_g, a part of the emitted electrons 12 which arrive at the boundary 9 after having followed a path 13 through the n-type semiconductor layer 5, have sufficient energy to cross that boundary 9 and enter into the vacuum.

[0027] In order to meet the above-mentioned first and second conditions, appropriate materials are selected for the first metal electrode 4 and for the n-type semiconductor layer 5. For the n-type semiconductor layer 5, a semiconductor material is selected with a band gap energy E_g higher than the electron affinity χ. For the first metal electrode 4, a metal is selected with a relative low work function Φ_M so that the energy barrier height Φ_B is not too high for tunnelling to be possible at relative low voltages and with obtainable impurity concentrations in the n-type semiconductor layer.

[0028] By preferences barium (Ba) is selected as material for the first metal electrode 4, and barium oxyde (BaO) is selected as material for the n-type semiconductor layer 5. A typical BaO layer thickness is 50 nanometers. A typical size of a cold cathode electron-emitting device according to the invention is 10 micrometers by 10 micrometers.

[0029] Other materials are known which can appropriately be used as materials for the first metal electrode 4 and the n-type semiconductor layer 5. ZnS can be used as material for the n-type semiconductor layer 5, by preference with a mono-atomic layer of caesium (Cs) at the boundary 9 with the vacuum 10 in order to decrease the electron affinity χ and to help in this way the hot electrons 12 to pass through the boundary 9 and escape into the vacuum 10. In Fig. 3 is shown a part of a cross sectional view of the first embodiment, whereby on the n-type semiconductor layer 5 is deposed a mono-atomic layer 14 of a material with a low work function as for instance Cs, in order to decrease the electron affinity χ of the n-type semiconductor layer 5.

[0030] In Fig. 4 is shown a cross sectional view of a second embodiment which is a cold cathode electron-emitting device 10 similar to the first embodiment, however with a symmetrical structure of a first metal electrode 4, a second metal electrode 15, a n-type semiconductor layer 5 and an insulating substrate 3. The first metal electrode 4 and the second metal electrode 15 are by preference made of the same material, and are positioned under the same n-type semiconductor layer 5. The contact between the first metal electrode 4 and the n-type semiconductor layer 5 is a first Schottky junction 6. The contact between the second metal electrode 15 and the n-type semiconductor layer 5 is a second Schottky junction 16. The materials used for the first and second metal electrodes 4 and 15, and the n-type semiconductor layer 5 of this second embodiment are the same as the ones used for the first metal electrode 4 and the n-type semiconductor layer 5 of the first embodiment. The two Schottky junctions 6 and 16 emit electrons through tunnelling when reverse biased, as explained hereinabove (first embodiment). However, the two Schottky junctions 6 and 16 cannot emit hot electrons at the same time. When tunnelling occurs at one of the two Schottky junctions 6 or 16 which is reverse biased, the other Schottky junction is forward biased.

[0031] To emit electrons from both Schottky junctions 6 and 16, an AC voltage source V_S is applied to the cold cathode electron-emitting device 10. A capacitor C can optionally be put in series with the AC voltage source V_S in order to obtain current driving as explained furtheron. The voltage over the cold cathode emitting device 10 is substantially constant and is equal to the sum (further called V_{SS}) of the Zener Voltage V_Z over the reverse biased Schottky junction and the voltage V_F over the forward biased Schottky junction. Thus $V_{SS}=V_Z+V_F$. The amplitude of the voltage source V_S is chosen higher than V_{SS} for the cold cathode electron-emitting device 10 to be current driven. The main value of the current corresponding to the flow of hot electrons of one Schottky junction is approximately :

$$Ihot = f \cdot (VS\text{-}VSS) \cdot \frac{C}{2}$$

where $C>$ is the value of the capacitor C, and f is the frequency of the voltage source V_S. More than 5% of the hot electrons emitted at the two Schottky junctions 6

and 16 cross the corresponding boundaries 9 and 17 and enter into the vacuum where they are collected by an anode plate 2 supplied by a source V_A as in the first embodiment.

[0032] It is preferred that the cold cathode electron-emitting device 10 is current driven because then, the electron emission is substantially stable and independent on temperature. Current drive is not limited to the use of one single capacitor. One or more capacitors and one or more cold cathode electron-emitting devices can be combined with one or more voltage sources. In such a combination, the cold cathode electron-emitting devices may have different operating voltages over their terminals and may have different emitting areas. The capacitors may have different values.

[0033] Current drive can also be realised by putting a resistor and a voltage source in series with a cold cathode electron-emitting device. The voltage source can either be a DC or an AC voltage source, and the cold cathode electron-emitting device can either be asymmetrical as shown in Fig. 1 or symmetrical as shown in Fig. 4. Analogously with what has been described for current driving cold cathode electron-emitting devices using capacitors, one or more resistors can be combined with one or more cold cathode electron-emitting devices, and one or more voltage sources.

[0034] Because of the symmetrical structure of the second embodiment of the present invention as shown with Fig. 4, the contact between the n-type semiconductor layer 5 and the second metal electrode 15 is the second Schottky junction 16; it is not an ohmic contact. In Fig. 5 is shown an energy diagram of the second Schottky junction 16 when forward biased. No hot electrons are emitted from such a forward biased Schottky junction. Compared to the energy diagram of the reverse biased first Schottky junction 6 shown in Fig. 2, the metal electrode being the second metal electrode 15 has a positive voltage V_F with respect to the n-type semiconductor layer 5. The working principle of the second Schottky junction 16 is equal to the working principle of a state-of-the art Schottky diode; some of the majority carriers in the conduction band of the n-type semiconductor layer 5 have enough kinetic energy by thermal agitation to overcome the energy barrier, which is Φ_B, lowered by a value $q.V_F$ because of forward biasing. V_F is typically lower than 1 volt.

[0035] A third embodiment of the present invention is shown in Fig. 6 and is a symmetrical cold cathode electron-emitting device 10 in series with a capacitor C, both mounted on the same substrate 3 and by preference made with the same technology, for instance thin film technology. The capacitor C consists of three layers. The first layer of the capacitor C is a metal electrode which can be one of the two metal electrodes 4 or 15 of the cold cathode electron-emitting device 10. In Fig. 6, the first layer of the capacitor C is formed by the second metal electrode 15. The first layer of the capacitor C can also be a layer making an ohmic contact with one of the two metal electrodes 4 or 15 of the cold cathode electron-emitting device 10. The second layer of the capacitor C is an insulator layer 18. The third layer of the capacitor C is a metal electrode 19, typically made of aluminium (Al). For the connections of the cold cathode electron-emitting device 10 and capacitor C combination as shown on Fig. 6 is used the metal electrode 19 being the third layer of the capacitor C and a metal connection electrode 20 having an ohmic contact with the first metal electrode 4, both connections by preference being made of the same material, for instance aluminium.

[0036] A fourth embodiment is shown in Fig. 7. It is a symmetrical cold cathode electron-emitting device 10 of which the n-type semiconductor layer is divided in two parts. In a first part of the semiconductor layer 22, the concentration of donor impurities is high (highly doped). In a second part of the semiconductor layer 23, the concentration of donor impurities is relatively low (weakly doped), for instance 10% of the concentration of donor impurities in the first part of the semiconductor layer 22. The thickness of the parts 22 and 23 of the semiconductor layer is not necessarily equal over the whole cross section of the n-type semiconductor layer. The thickness of both parts 22 and 23 of the semiconductor layer within the active areas 24 from which the electron emission 13 occurs is small (typically a few tens of nanometers). The electric field within the weakly doped second part of the semiconductor layer 23, between an electron-emitting metal electrode 4 or 15 and the highly doped first part of the semiconductor layer 22, is approximately constant when the Schottky junction 6 or 16 between the n-type semiconductor layer and the metal electrode 4 or 15 is reverse biased. The depletion region within the n-type semiconductor layer is then more or less constrained to the weakly doped second part of the semiconductor layer 23. The Zener voltage at which tunnelling happens is mainly determined by the thickness of the second part of the semiconductor layer 23 in the active area 24 and less dependent on the concentration of impurities in the first and second parts 22 and 23 of the semiconductor layer. As a consequence, the Zener voltage, being typically 3 volts, can be better reproduced.

[0037] In the embodiment as shown in Fig. 7, the thickness of the weakly doped second part of the semiconductor layer 23 is higher at the edges of the metal electrodes 4 and 7. This causes a decrease in the strength of the electrical field in the depletion region of the n-type semiconductor layer at the edges of the metal electrodes 4 and 7 instead of an increase of the electrical field which could otherwise occur because of geometrical effects as for instance rounding of the metal electrodes 4 or 7 at their edges. A higher field strength at the edges of the metal electrodes 4 or 7 is not wanted because it can constrain the tunnel effect to the edges of the active areas 24 where the conditions for electron emission are not optimal and more difficult to control.

When the Schottky junctions 6 and 16 as in Fig. 7 are for instance formed of a combination of Ba and BaO materials, metal electrodes 4 and 7 made of Ba can be deposed and covered by a weakly doped BaO second part of the semiconductor layer 23 which is thicker nearby the edges of the Ba metal electrodes 4 and 7. A highly doped first part of the n-type semiconductor layer 22 can be deposed on the weakly doped second part of the semiconductor layer 23 forming so a conductive path in the channel between the two active areas 24. The connection electrodes 20 of the cold cathode electron-emitting device 10 to a voltage source can be made of for instance aluminium.

Claims

1. A cold cathode electron-emitting device (1;10) comprising at least a n-type semiconductor layer (5) and a first metal electrode (4), characterised in that said n-type semiconductor layer (5) and said first metal electrode (4) form a first Schottky junction (6) through which, when said first Schottky junction (6) is reverse biased, hot electrons are injected from the first metal electrode (4) into the n-type semiconductor layer (5) by tunnelling, said hot electrons having such an energy and said n-type semiconductor layer (5) being of such a material that a part of the hot electrons can flow through the n-type semiconductor layer (5) and penetrate directly from the n-type semiconductor layer (5) into a vacuum.

2. Cold cathode electron-emitting device (1;10) according to claim 1 characterised in that it presents a range of operating states such that at least 5% of the electrons which have tunnelled through the first Schottky junction (6) are emitted into the vacuum, the voltage over the cold cathode electron-emitting device being lower than 10 volts.

3. Cold cathode electron-emitting device (1;10) according to one of the previous claims, wherein the material of the n-type semiconductor layer (5) is of the II-VI type.

4. Cold cathode electron-emitting device (1;10) according to claim 3, wherein the material of the n-type semiconductor layer (5) is ZnS.

5. Cold cathode electron-emitting device (1;10) according to claim 3, wherein the material of the n-type semiconductor layer (5) is BaO, and wherein the material of the first metal electrode (4) is Ba.

6. Cold cathode electron-emitting device (1;10) according to one of the previous claims, wherein the surface of the n-type semiconductor layer is coated with an ultra thin layer of Cs or another material with a low electron work function.

7. Cold cathode electron-emitting device (1) according to one of the previous claims comprising furthermore a second metal electrode (7) in contact with said n-type semiconductor layer (5) wherein the contact (8) between said second metal electrode (7) and said n-type semiconductor layer (5) is an ohmic contact.

8. Cold cathode electron-emitting device (10) according to one of the claims 1 to 6, comprising furthermore a second metal electrode (15) in contact with said n-type semiconductor layer (5) wherein the contact between said second metal electrode (15) and said n-type semiconductor layer (5) is a second Schottky junction (16).

9. Cold cathode electron-emitting device (1;10) according to one of the previous claims, constructed using thin film technology.

10. A circuit for current driving one or more cold cathode electron-emitting devices according to any of the previous claims, comprising at least one capacitor, at least one cold cathode electron-emitting device, and at least one AC voltage source.

11. A circuit for current driving one or more cold cathode electron-emitting devices according to one of the claims 1 to 9, comprising at least one resistor, at least one cold cathode electron-emitting device, and a voltage source.

12. A circuit according to claim 10 or 11, characterised in that the cold cathode electron-emitting devices and the capacitors or resistors are mounted on the same substrate.

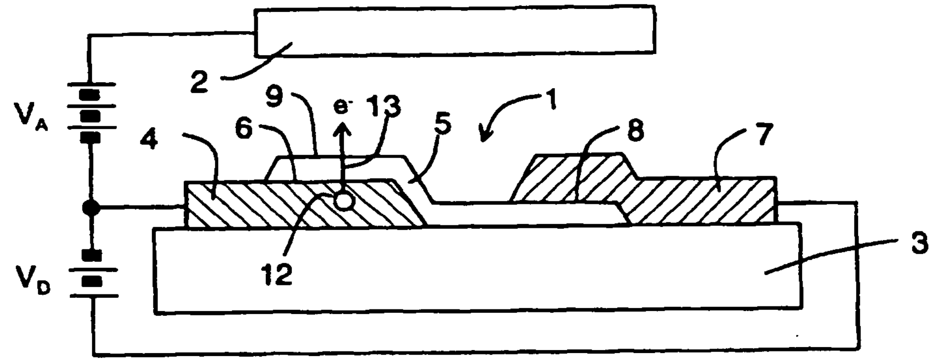

Fig. 1

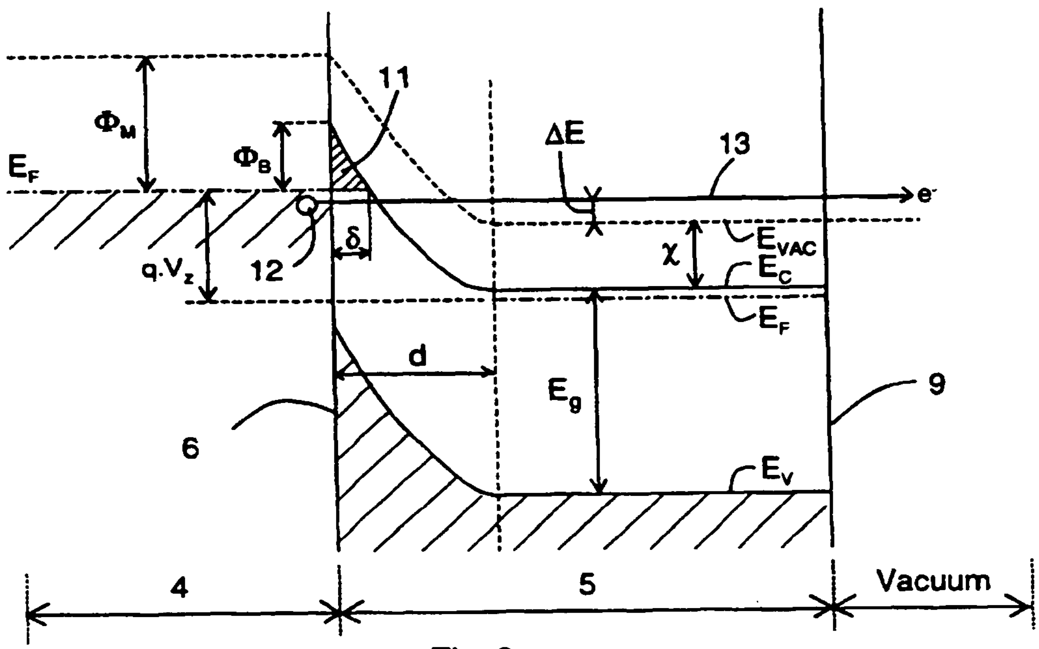

Fig. 2

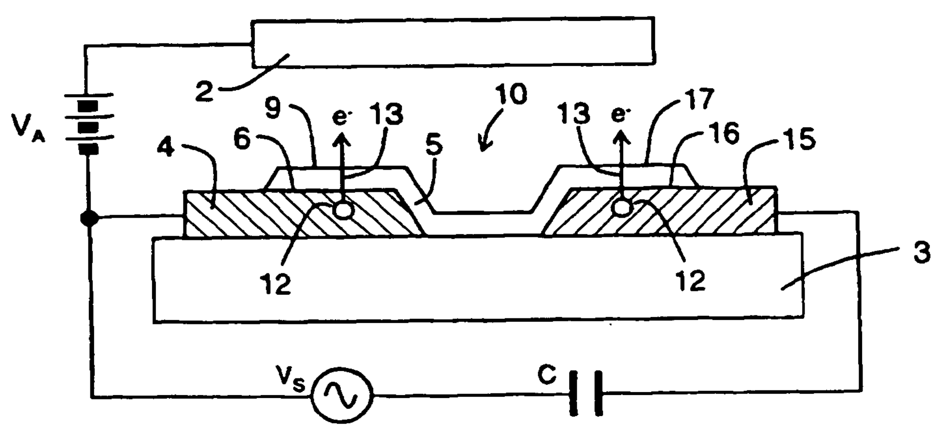

Fig. 4

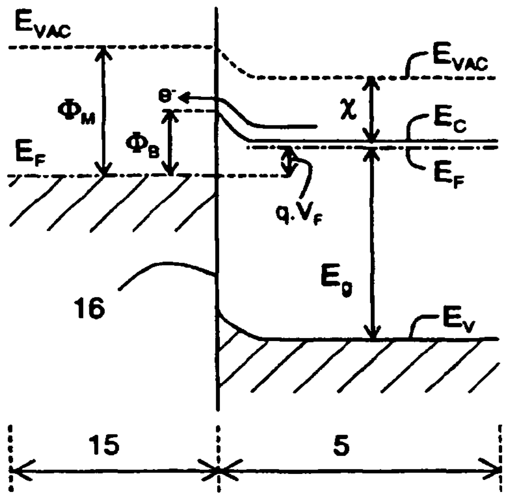

Fig. 5

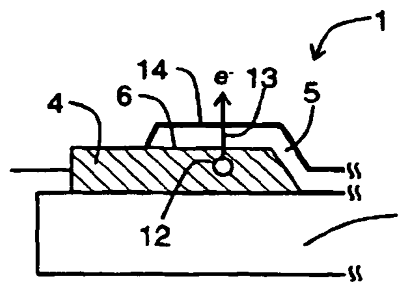

Fig. 3

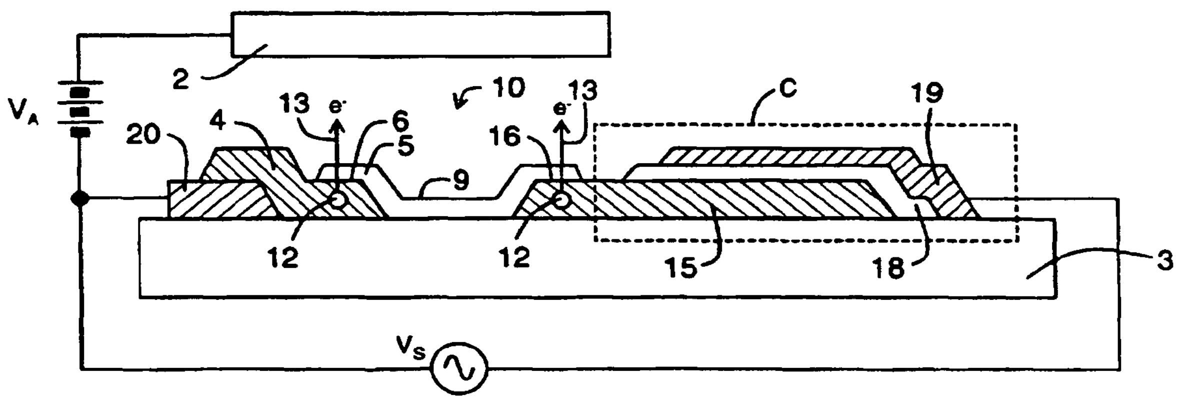

Fig. 6

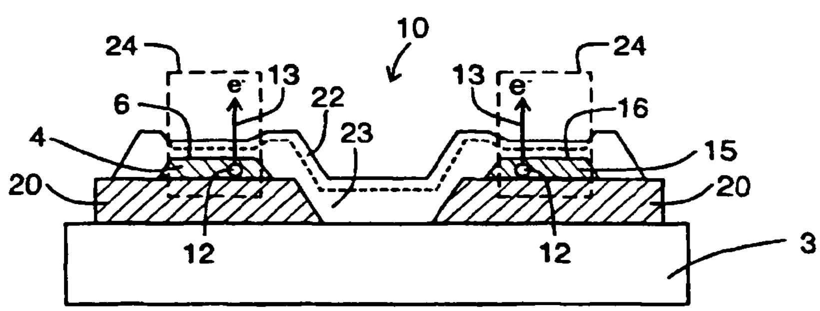

Fig. 7

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 98 87 0112

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	GEIS M W ET AL: "DIAMOND EMITTERS FABRICATION AND THEORY" May 1996 , JOURNAL OF VACUUM SCIENCE AND TECHNOLOGY: PART B, VOL. 14, NR. 3, PAGE(S) 2060 - 2067 XP000621834 * page 2062 * ---	1	H01J1/30
A	US 5 233 196 A (OKUNUKI MASAHIKO ET AL) 3 August 1993 * column 8, line 9 - column 9, line 23; claims 7,9 * ---	1	
A	US 3 808 477 A (SWANK R) 30 April 1974 * column 2, line 54 - column 3, line 28; claims 1,2; figure 1 * ---	1	
A,D	US 3 098 168 A (PIERRE AIGRAIN) 16 July 1963 * claims 1-9 * ---	1	
A	WO 97 39469 A (MASSACHUSETTS INST TECHNOLOGY) 23 October 1997 * page 9, line 9 - line 20; figure 4 * ---	1	TECHNICAL FIELDS SEARCHED (Int.Cl.6) H01J
A	US 3 500 102 A (CROST MUNSEY E ET AL) 10 March 1970 * column 2, line 62 - line 68; claim 1; figure 1 * ---	1,3,5	
A	US 2 960 659 A (A.BURTON) 15 November 1960 * column 5, line 48 - line 74; claim 1; figure 6 * --- -/--	1	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	4 November 1998	Van den Bulcke, E

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

BEST AVAILABLE COPY

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 98 87 0112

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	GEIS M W ET AL: "THEORY AND EXPERIMENTAL RESULTS OF A NEW DIAMOND SURFACE-EMISSION CATHODE" 1997 , THE LINCOLN LABORATORY JOURNAL, VOL. 10, NR. 1, PAGE(S) 3 - 18 XP000749210 * page 4 - page 6 * ---		
A	A.KUDINTSEVA ET AL.: "a cold emitter with semiconductor-metal film structure" RADIO ENGINEERING AND ELECTRONIC PHYSICS, vol. 13, no. 8, 1968, pages 1329-1330, XP002083048 * page 1329 - page 1330 * -----		
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	4 November 1998	Van den Bulcke, E

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document